Test-retest validity of acoustic pharyngometry measurements

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BACKGROUND: **Acoustic reflectometry is a relatively new technique that quantifies upper airway obstruction. The oropharyngeal airway is geometrically complex and variable; therefore establishing a standard operating protocol and understanding the possible sources of artifacts are of great importance in obtaining reliable results. This work aims at assessing the repeatability of pharyngeal cross-sectional area measurements obtained from normal and snoring individuals.**

METHODS: **Twenty adult normal volunteers (16 men and 4 women; mean age, 35.9 years) and 10 adult snorers (9 men and 1 woman; mean age, 36.4 years) were examined by acoustic reflectometry following the developed standard operating protocol.**

RESULTS: **Measurements of pharyngeal cross-sectional area are analyzed in 2 groups. In normal subjects where mean pharyngeal cross-sectional area in the first session was 3.187 cm^2, in the second session (same-day test-retest), the mean pharyngeal cross-sectional area was 3.239 cm^2, and in the third session 7 to 10 days later (day-to-day test-retest), it was 3.245 cm^2 ($P > 0.4$). In a second group of snoring patients where mean pharyngeal cross-sectional area in the first session was 2.244 cm^2, in the second session, mean pharyngeal cross-sectional area was 2.237 cm^2, and mean pharyngeal cross-sectional area in the third session (7 to 10 days later) was 2.238 cm^2 ($P > 0.9$).**

CONCLUSIONS: **These results show that repeatability of acoustic reflection results can be achieved following the standard operating protocol.**

SIGNIFICANCE: **The study results add to the reliability of this technique in assessing the pharyngeal airway in patients with snoring and obstructive sleep apnea.** (Otolaryngol Head Neck Surg 2004; 130:223-8.)

Acoustic reflectometry is a relatively new technique that quantifies upper airway obstruction. The basic physical principles are that an audible sound signal is generated at the bottom of a tubular probe (wave tube) and transmitted into the cavity examined via an anatomically fitted coupler (mouth piece). The acoustic pulse is partially reflected when it encounters an area (impedance) change. The amplitude and temporal changes in the reflected pulse compared with the incident pulse are used to calculate, by computer, the changes in airway cross-sectional area.[1-3] The technique is rapid and noninvasive and requires minimal cooperation from the subject.[1] It is used to assess the pharyngeal cross-sectional area in patients with sleep apnea.[4]

The accuracy of acoustic measurements of the nose[2,5-7] and pharyngotracheal region[8-10] has been demonstrated. Unlike the nose, the oropharyngeal airway is geometrically more complex and variable[11,12] and includes mobile structures (soft palate and tongue); therefore establishing a standard operating protocol and understanding of the possible sources of artifacts is of great importance in obtaining reliable results. Of equal importance is testing the repeatability of measurements obtained to ensure validity of both the technique and results.

The aim of this work was to assess the repeatability of pharyngeal cross-sectional area measurements obtained from normal and snoring individuals on the basis of intersession and intrasession measurements to evaluate the standard operating protocol and to identify sources of artifacts as well as the physical limitations of the technique.

SUBJECTS AND METHODS

Twenty adult normal volunteers (16 men and 4 women; mean age, 35.9 years) and 10 adult snorers (9 men and 1 woman; mean age, 36.4 years)

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were examined by acoustic pharyngometry (Eccovision acoustic pharyngometer [E. Benson Hood Laboratories, Pembroke, Mass.]); criteria for selecting normal volunteers were as discussed.[13] Snoring patients were examined during the process of assessment of the upper airway (which included also Muller's maneuver, lateral cephalometry, and acoustic rhinometry whenever a nasal factor is suggested as contributing to the condition). All subjects were examined following the developed standard operating protocol.

Standard Operating Protocol

1. Patient position: The subject is seated in a firm chair with a tall, straight back, adjustable seat height and adjustable head support to maintain the head in neutral position and the wave tube in proper position.
2. Patient considerations: The test is done during normal quite breathing; therefore the subject is allowed to sit down for a while during that time he or she is briefed about the test and its nature. The patient is instructed to remain still during the test and fix the gaze at a point on the opposite wall at the same gaze level. Patients were also told to think silently of "oooh" to put the tongue in a relaxed position on the floor of the mouth and keep the velum closed as vowel phonation is through the mouth only.[14]
3. Mouthpiece: The mouthpiece is made of rubber and is designed to be placed with the teeth against the flange, biting down on the protruding tabs, and with the lips over the flange to form acoustic seal.[14]
4. Positioning of the wave tube: The tube is placed horizontally parallel to the floor, preferably held in position by an assistant rather than by the subject, while the operator is working on the computer and watching the patient and equipment setup.
5. Operator: Some training of the operator or a volunteer before working with the equipment is helpful to become familiar with the equipment and to consistently obtain a reproducible result. It is always important to watch the test setup rather than the computer screen. Obtaining results of 4 tests on the same session to calculate the coefficient of variance[13] adds to the accuracy of results and lessens operator bias.
6. Number of tests: Each subject was examined for a first time after a rest period after arrival at the sleep laboratory and then 2 to 3 hours later in a second session (same-day test-retest) and a third time 7 to 10 days later (day-to-day test-retest). Each examination was performed 4 times, and the coefficient of variance was calculated; when it was found to be between 5% and 10%,[13] the test result was documented.

Statistical Analysis

Statistical analysis was made using Statistica 5 computer software (StatSoft, Inc., Tulsa, Ok.).

RESULTS

Measurements of pharyngeal cross-sectional area were analyzed in 2 groups, normal subjects ($n = 20$) and snorers ($n = 10$).

Normal Volunteers

Mean pharyngeal cross-sectional area in the first session was 3.187 cm^2; in the second session (same-day test-retest), mean pharyngeal cross-sectional area was 3.239 cm^2, and in the third session (day-to-day test-retest), it was 3.245 cm^2. One-way analysis of variance (ANOVA) was applied to test the significance of the difference in results, with $P = 0.440$ indicating no statistically significant difference among measurement of pharyngeal cross-sectional area taken in the 3 sessions. Comparing the mean pharyngeal cross-sectional area obtained in a previous study of 350 normal volunteers[14] and the means obtained in each of the sessions in this study, $P = 0.9213$ for the mean in the first session, $P = 0.5192$ for the mean in the second session, and $P = 0.4652$ for the mean in the third session. This indicates no statistically significant difference of the pharyngeal cross-sectional area in both studies, where the same standard operating protocol was used (Table 1).

Snorers

Mean pharyngeal cross-sectional area in the first session was 2.244 cm^2; mean pharyngeal cross-sectional area in the second session was 2.237 cm^2, and mean pharyngeal cross-sectional

Table 1. Basic statistics of pharyngeal cross-sectional area in normal volunteers

Area	n	Mean area (cm^2)	SD	SE
Session 1	20	3.187	0.249	0.0556
Session 2	20	3.239	0.0790	0.0177
Session 3	20	3.245	0.0811	0.181

Table 2. Basic statistics of pharyngeal cross-sectional area in snoring patients

Area	n	Mean area (cm^2)	SD	SE
Session 1	10	2.244	0.428	0.135
Session 2	10	2.237	0.424	0.134
Session 3	10	2.238	0.421	0.133

area in the third session was 2.238 cm^2. One-way ANOVA test was applied to test the significance of the difference in results, with $P = 0.987$ indicating no statistically significant difference in mean pharyngeal cross-sectional area obtained in the 3 sessions. Mann-Whitney rank sum test (a variant of the *t* test) was applied to test the significance of the differences between pharyngeal cross-sectional area in the normal volunteers and snoring patients; $P < 0.001$ in all cases, indicating a significant difference in pharyngeal cross-sectional area between snorers and normal volunteers (Table 2, Figs 1 and 2).

DISCUSSION

The introduction of the acoustic reflection technique offers a potentially quick and easy means for the assessment of the pharyngeal airway. This method is, however, not without its problems, and there is at present no agreed-on method of collecting data from the cavity examined by this technique.

The accuracy of the acoustic reflections method for the evaluation of human airway geometry is determined by the physical limitations of the technique and by the in vivo deviations from the assumptions of the technique. The assumptions inherent in the method of area inference from acoustic pulse response measurements may be divided broadly into 2 categories[9,10,15]: (1) those that arise from idealization as to the physiologic behavior of the measured structures (assumptions from this category include 1-dimensional wave propagation, rigidity of airway walls, and uniform gas composition throughout the wave tube and the measured structure) and (2) assumptions dealing with computational methods associated with area calculations (idealizations from this category include infinite measurement bandwidth and zero inconsistency error).

The common sources of error in acoustic reflection study of the pharynx are as follows:

1. Patient positioning: This may play an important role in determining the pharyngeal area by acoustic reflectometry. Flexion of the neck and back and rising of the shoulders, which occurs near residual volume, may compress the pharynx and reduce its cross-sectional area.[16] Eckmann et al[17] and Tse et al[18] studied the effect of head/neck position and found that the variation in pharyngeal volume varies significantly between the head in neutral position, 45-degree extension, and more extended position. In the present study, posture control was attempted by adjusting the height of the chair and the wave tube, fixing the gaze to a point at the opposite wall on the same gaze level, resting the head on a head rest fixed to the chair and continuous monitoring of any change in the patient's posture during examination.
2. Physiologic variations in pharyngeal airway cross-sectional area during breathing: As pharyngeal area varies significantly with lung volume[9,16,19,20], this factor also requires standardization. During quite normal breathing, variability in pharyngeal cross-sectional area is not significantly influenced by changes in lung volume or differences in muscle activation that occur between inspiration and expiration.[9] Bradley et al[21] and Fouke and Strohl[22] have shown that lung volume changes in the tidal range do not produce significant changes in the pharyngeal cross-sectional area. Thus modest changes in lung volume during quite normal breathing apparently do not contribute to the variability of measures in pharyngeal cross-sectional area. Performing the test at quite normal breathing, in this study, was attempted by keeping the subject in the sleep

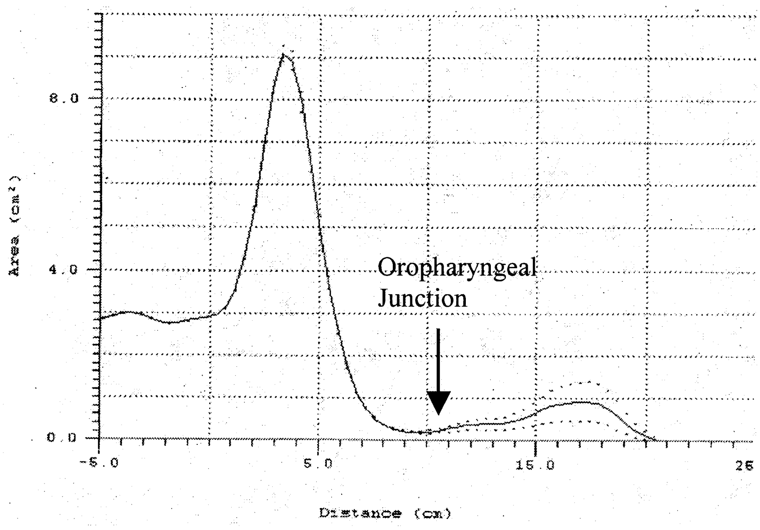

Fig 1. A snoring acoustic pharyngogram.

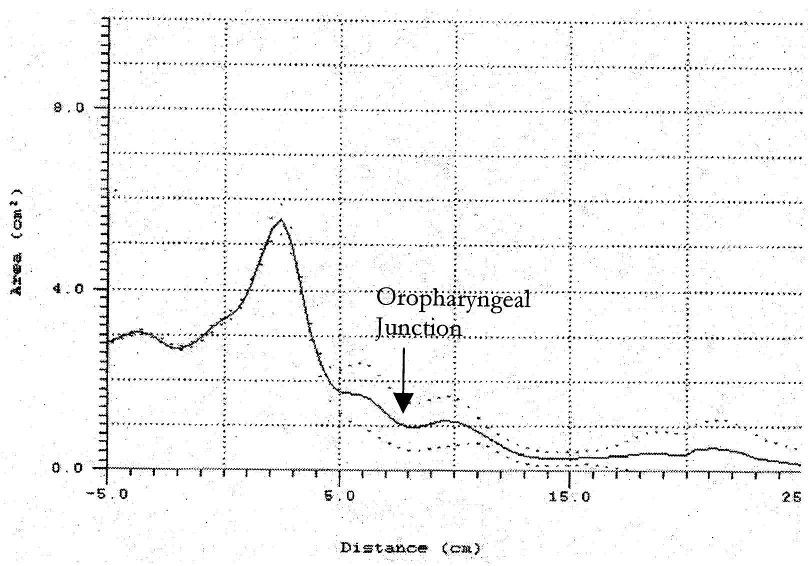

Fig 2. An obstructive sleep apnea patient's acoustic pharyngogram.

lab for a reasonable period of time to alleviate possible increased respiratory rate because of physical effort, anxiety, or apprehension. For many subjects, it might be better to start the test without any comment on what to do with one's respiration; only if fluctuations of respiratory rate are noticed are patients instructed about the importance of keeping normal quite respiration.

3. Mouthpiece and wave tube position: Earlier models of equipments used facemasks to permit the introduction of acoustic impulse.[10,23] This had the disadvantage of opening the mouth during testing, which elevates the soft palate from the tongue, thus altering pharyngeal anatomy.[24] Proper anatomically fitting mouth pieces, in addition to preventing acoustic leak, achieve greater spatial resolution and greater bandwidth by eliminating the relatively large transverse dimension of the mouth, thus decreasing interference with planar wave propagation.[10] As for the material of the mouthpiece, Rubinstein et al[25] suggested that a standard rubber

mouthpiece yields results comparable to those achieved with a custom-made wax mouthpiece. Brooks et al[26] studied the effects of custom made wax mouthpieces and ready made rubber ones and concluded that each subject responds to the mouthpiece in a consistent manner despite the difference in results obtained with different types of mouth pieces. They also suggested that the factors affecting pharyngeal response to the mouthpiece include physical distention of the pharynx, reflex activation of pharyngeal muscles, and difference in cheek position as possibly affected by the mouthpiece. The position and height of the wave tube have to be adjusted with the height of the chair so that each subject feels comfortable and relaxed. The wave tube has to be fixed in position during the examination.[26]

4. Position of the velum and the tongue: Changing the position of the velum and tongue is an important source of error in this technique. An open velum causes acoustic impulses to pass through the nose to the external environment, creating another form of acoustic leak. Moreover, when this occurs, assumptions about 1-dimensional wave propagation are violated. The velum open plots overestimate cross-sectional area measurements and show greater configuration variability (9).

The role of the tongue in determining pharyngeal area and the curve configuration is not yet definitely localized; however, the curve pattern and measurements vary widely if neutral position of the tongue is not maintained. The direct mechanical effect of altering the tongue position can be minimized by bulky mouthpieces that fix the tongue; yet this may result in altering of the cheeks and oropharyngeal geometry.[12] In this study, thinking of a silent “oooh” (as suggested by the manufacturer) was found to be helpful because it puts the tongue in a relaxed position on the floor of the mouth and closes the velum, preventing the nasal cavity area from being measured.

In general, artifacts in acoustic reflection technique manifest in one of two ways[27]: either as widely spaced error bars or lines around the produced curve or as failure to obtain close results after taking 3 or 4 rapid consecutive traces of acoustic pulse.

The acoustic reflection technique has been used to assess pharyngeal cross-sectional area. The technique has been previously applied to study the pharynx, glottis, and trachea in humans in vivo. The technique has been validated against computed tomography scans and experimental models.[28] Testing the intersession and day-to-day variability of pharyngeal measurements is a part of testing the validity of the technique. Results of this study show that measurements of pharyngeal cross-sectional area in different session on the same day did not differ significantly from those obtained in different days. This was also the case in the group of snorers who were subjected to acoustic reflectometry. Moreover, results of normal subjects did not differ significantly from the results of another study performed on a much bigger number of normal subjects.[13]

Provided that a standard operating protocol is adopted and maintained, repeatability of acoustic reflection results can be achieved. This adds to the reliability of this technique in assessing the pharyngeal airway in snorers and patients with obstructive sleep apnea.

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